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Research paper

Development of an Embedded Palm Vein Imaging Prototype

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Abstract

This paper shares one of the available options in developing an embedded palm vein imaging prototype. The prototype was developed by the Raspberry Pi SBC to promote portability of the embedded system. With an integrated illumination circuit utilizing two near infrared (NIR) peak wavelengths of 850 nm and 870 nm, this paper explores the ability of the prototype to capture palm vein pattern information. The prototype program, and image analysis were executed by Python language environment and OpenCV module binding. The captured palm images were compared with palm image datasets from the Chinese Academy of Sciences' Institute of Automation (CASIA) and the Hong Kong Polytechnic University (PolyU). The comparison was done in terms of observation of the image recorded and palm vein pattern revealed, and also through image assessment metrics. Results show that palm images captured by the prototype has the ability to record vein pattern information in the image with pixel-by-pixel similarity rate of 96.54% (median) for the extracted vein pattern, compared to the CASIA (median: 96.07%) and PolyU (median: 90.99%) datasets. As such, the developed prototype can be enhanced its usage not only for biometric acquisition, but also for medical purpose.

Keywords: *Embedded System; Palm Vein Biometric; Prototype Development; Single Board Computer.*

1. Introduction

Biometric system is gaining wide interest as optional tools for authentication and verification. Most of available literatures share a number of advantages offered by biometric technology and even demonstrated its potential in discriminating identities for recognition purpose [1]. Among those are biometric data is solely owned by the individual hence its usage required specific consent and permission; compare to conventional use of passwords or access card which can be acquired by third parties. Reported works in palm vein recognition revealed variety of algorithms and approaches that can be adopted to improve its recognition performance [2], [3]. Efforts in developing a robust acquisition device does not significantly highlighted as major issue in biometric authentication is on its recognition accuracy [4]. Still, the recognition accuracy is highly affected by the acquisition system, whereas if the acquired biometric data is recorded effectively, it will indirectly increase the recognition accuracy.

Works shared on hand vein image acquisition device are mostly on its development and setup to be used in a dedicated and controlled space [5]. The image acquisition device developed in that way is more suitable as testing or experimental platform for research purpose. In some device, there is a need to ensure that the surrounding condition to be dark to properly capture vein pattern information [6]. In others, a guidance or marker is needed to ensure correct hand area is imaged to guide user during the acquisition process [7]. Although the shared published works proposed a reliable biometric acquisition system that can capture the biometric data, it is worth to explore if there is an alternative such that the image acquisition device can capture vein information without additional props for controlled surrounding and needs. This paper aims to share one of the optional configuration that can capture vein information without the need of controlled surrounding.

Two main literatures motivate our work in this research. The first one is based on a work done in iris biometric system where a single board computer (SBC) had been used as processor platform in developing the system [8]. The second one is based on a work done in development of multiple hand features biometric acquisition system [9]. The latter work shows that it is possible to have a simplified yet robust image acquisition system. The former shows that a smaller yet easier to port system can be made possible through the use of SBC as its processor platform. By combining the works shared in these two main research, an alternative approach for the development of a palm vein imaging prototype is presented in this paper.

This paper is organized such that Section 2 presents the review on vein imaging application area. Section 3 illustrates the prototype development and configuration. Section 4 demonstrates the prototype graphical user interface (GUI), while its method of assessment is given in Section 5. Section 6 presents the result and discussion in terms of the visualization of the vein pattern acquired, and the assessment of the acquired dataset compared to other palm image datasets. The last section summarizes the work done and future research recommendation.

2. Vein imaging Application

Vein pattern can be detected using near infrared (NIR) or far infrared (FIR) spectrum [10] as it resides under the skin, and is not easily interpreted by the use of imaging system in visible spectrum. The vein pattern detected is useful for biometric authentication purpose [11] and for medical application [12]. In biometric authentication field, the reported work revealed varieties in the vein image acquisition device and configuration, but the main concern still revolves in the used of NIR spectrum in visualizing the vein pattern. Although FIR allows vein pattern to be imaged, its image sensor is generally costs higher (as it needs special thermal sensor to enable the imaging), compared to NIR image sensor; which can be directly recorded through commercial cameras with a special tweak in the device. Most of the works done are in its experimental phase, in which the device setup is more suitable to be tested and applied in a dedicated large space (e.g. research lab) [13].

In medical field, efforts in developing a vein detector system had recently been explored following the usefulness of such system for medical practitioners and educational purposes [14]. In separate work, a vein detector system was developed comprises of an Android-based device and a NIR illumination circuit, utilized to enhance the portability of the system and its mobility [15]. Several existing devices had also been compared in the same work in terms of its ease-of-use and benefits for medical practitioners. Others reported the use of mobile phones camera and integrated NIR illumination circuit to enable visibility of vein pattern [16].

In this paper, palm area will be used to demonstrate the prototype application. This is because, palm being part of hand, is publicly acceptable part of human body that can be used to access vein pattern, compared to other parts of human body [1]. Furthermore, palm area is unobstructed by skin colour or hair, making it favourable option to validate the prototype.

3. Prototype development

The prototype development is divided into two works which are: (1) hardware configuration, and (2) system operation.

3.1. Hardware configuration

Hardware for the prototype is as illustrated in Fig. 1. Vein image will be captured by the NIR illumination circuit, and stored in the Raspberry Pi SBC platform for further processing. During the image acquisition process, user palm has to be placed facing the camera integrated in the NIR illumination circuit shown in Fig. 2, in unguided way. The proposed distance between the palm and the camera is 13 ± 1 cm because it is within this distance that the whole palm area is within the field-of-view (FOV) of the camera. Interaction with the prototype was done through a touch-screen and wireless mouse attached to the SBC. The connection to these two devices is via the USB port in the SBC. Images captured are stored in an SD card of the SBC, in which the processing involved for the image analysis will also be done in the same platform. The image analysis was done by OpenCV module [17] integrated with Python programming environment.

Raspberry Pi SBC being in compact size is a practical choice for the system development because it also offers Wi-Fi connectivity if it is connected to its WIPI module [18]. With this option, it can be connected to the Internet for cloud-based services and even as network sharing platform. Not only that, the SBC can become a webserver if it is configured by CherryPy environment, among one of the options [19]. This property allows greater possibility for the platform to be upgraded depending on its application needs. The use of touch-screen as interfacing device while simplifying the interaction, requires careful configuration so not to mix up the screen resolution and the SBC operating screen. The use of wireless mouse help compensates for GUI navigation assist in the prototype.

The core circuit of the prototype that enables the vein to be capture in the image is the NIR illumination circuit. The illumination circuit and Raspberry Pi SBC is connected via CSI connector following the image sensor integration. Top view configuration of the NIR illumination circuit is shown in Fig. 2. The circuit consists of eight LEDs with NIR peak wavelengths of 850 nm and 870 nm arranged in circular order. The circuit was constructed following the previous study on vein visualization in determining the best suitable NIR peak wavelength for the purpose [20]. The camera integrated in the circuit is a Pi NoIR CMOS camera, which is sensitive to NIR environment [21]. A layer of photo film is place in front of the camera to filter (block) the visible spectrum and enhance the NIR scene during the imaging process.

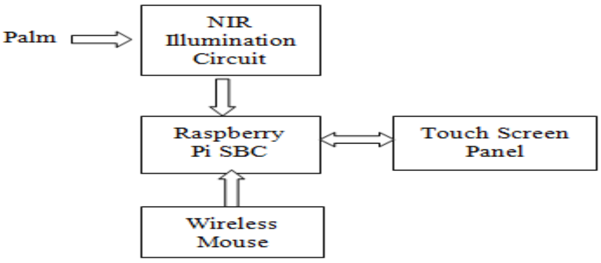


Fig. 1: Prototype configuration.

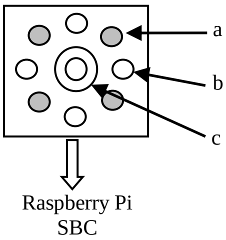


Fig. 2: NIR illumination circuit configuration showing: a = NIR LEDs with peak wavelength of 850 nm, b = NIR LEDs with peak wavelength of 870 nm, and c = Pi NoIR CMOS camera.

3.2. System operation

The flow of operation for the prototype is shown in Fig. 3. The program is written in Python language as it is the programming language that comes with Raspbian (official operating system of the SBC) [22]. Users will be presented with five options once the main program is executed on the platform.

Palm images will be captured if users made the choice to do so (options #1-2 in Fig. 3). The captured image will either be stored as template (option #1) or compared with the available dataset (option #2). Option #3 in Fig. 3 is a live preview of the palm image, with no record of the previewed image. The other two options (#4-5) allow the user to either quit the session and use the SBC for other purpose, or force hard shutdown of the system.

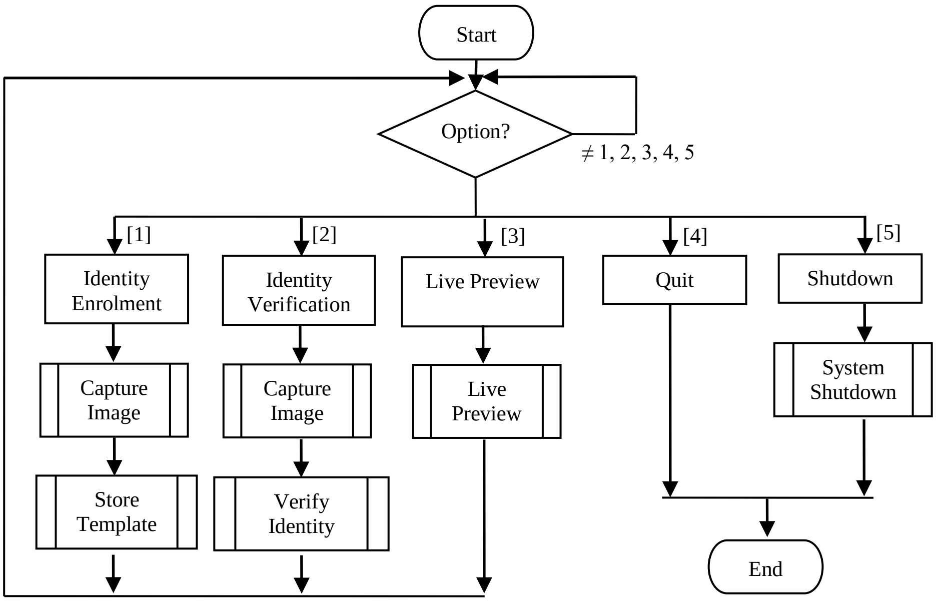


Fig. 3: Flowchart of the prototype operation.

4. System demonstration

The prototype’s welcoming screen is shown in Fig. 4 when the Python program was executed on the SBC. It can be seen in Fig. 4 that the five options in Fig. 3 were presented directly in its GUI environment as buttons in Fig. 4. Sample demonstrations are shown in Figs. 5 and 6 as pop-up messages for option #1 (Identity Enrolment) and option #4 (Quit) respectively.

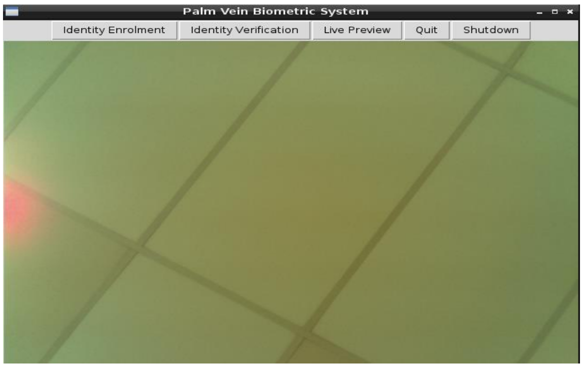
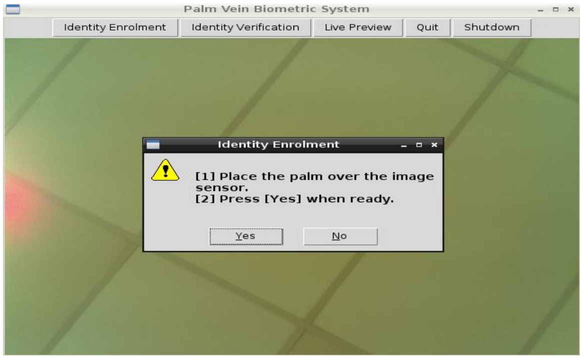
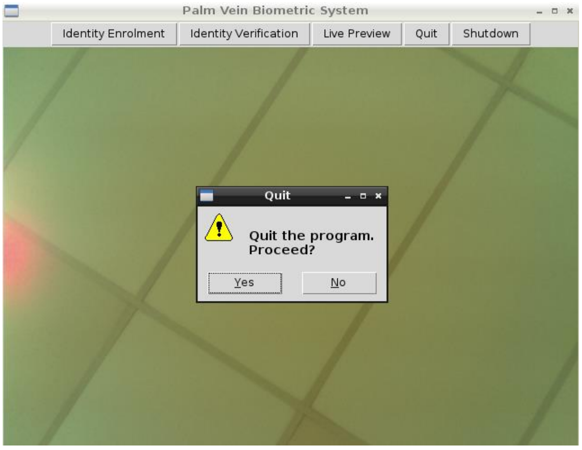


Fig. 4: Display screen of the prototype.



[1] Place the palm over the image sensor.
[2] Press [Yes] when ready.

Fig. 5: Pop-up message of the prototype when option #1 was chosen.



Quit the program. Proceed?

Fig. 6: Pop-up message of the prototype when option #4 was chosen.

5. Method of assessment and comparison

Images acquired by the prototype will be compared with samples of palm images from another two datasets. The first dataset was obtained from the Chinese Academy of Sciences' Institute of Automation (CASIA) [23] while the other was from the Hong Kong Polytechnic University (PolyU) [24]. The palm images were acquired by NIR peak wavelength of 850 nm (first dataset) and 880 nm (latter dataset). Images in both datasets are stored in an 8-bit greyscale JPEG format. These two datasets were originally captured for palm print images, but the source of illumination allows vein pattern to be capture in the image. Both datasets used CCD camera during the acquisition process [25], [26]. The difference of both datasets is in its acquisition nature, in which the former is unguided while the latter is guided by restricted markers to hold the hand area in place. Both were acquired in a controlled surrounding (enclosed in black/dark environment).

Comparison of the acquired image with these two datasets will be done in terms of: (1) observation of the vein pattern visualization after image enhancement processing, and (2) assessment of the enhanced palm images through signal-to-noise ratio (SNR), image contrast and extracted vein pattern similarity rate. The image enhancement processing executed on the three datasets comprises of processes shown in Fig. 7. The enhancement processing is needed to reveal the vein pattern recorded in the palm images. The processes consists of region-of-interest (ROI) extraction, image resizing, contrast enhancement (contrast limited adaptive histogram equalization) and noise reduction techniques (bilateral filtering and dilation operation) to help uncover the hidden vein pattern [27].

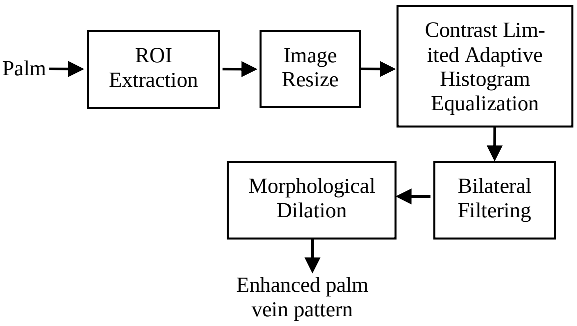


Fig. 7: Image processing for vein pattern enhancement [27].

Assessment of the enhanced images by SNR will show the quality of the acquired image, whether it is affected by its surrounding noise or equivalent. If the SNR of an image is high, it shows that the image is less prone to noise, which demonstrates a good image quality [28]. Assessment of the enhanced images by image contrast is calculated by Michelson contrast equation in (1) [29] where C_I is the Michelson contrast, L_{max} is the maximum luminance value and L_{min} is the minimum luminance value in the image. The range of Michelson contrast varies from 0.0 to 1.0, where the closer the value to 1.0 indicates the higher image contrast. Image with high contrast allows the object of interest in the image (vein pattern) to be better distinguished (visually interpreted) in the image.

$$C_I = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \tag{1}$$

The enhanced images will be further processed by Laplacian filtering and adaptive thresholding operation to extract the vein pattern [27]. The extracted vein pattern will be presented in white in the image, against a black background (non-vein features). Assessment of the extracted vein pattern similarity rate will be obtained through pixel-by-pixel similarity rate. The pixel-by-pixel similarity rate will be done by comparing the extracted vein in every six samples of each palm, with its reference pattern (obtained by vein image average) for the three palm image datasets. The pixel-by-pixel similarity rate can varies from 0% to 100% similarity where 100% score indicates perfect similarity. In assessing the similarity rate, the score signify the percentage of similar vein pattern extracted in the image. Hence, the pixel-by-pixel similarity rate that is closer 100% shows a good performance of the datasets.

6. Results and discussion

Results of the assessment methods explained in the previous section will be presented in this section. The first part of this section shares the observation of the vein pattern visualization after the image enhancement processing for the three datasets. The second part of this section presents the assessment results of the enhanced palm images through signal-to-noise ratio (SNR), image contrast and extracted vein pattern similarity rate.

6.1. Vein pattern visualization

Samples of palm images acquired by the prototype were compared with samples of palm images from the two datasets in Fig. 8. The vein pattern in the raw palm image does not directly distinguished in the images. The vein pattern can only be mapped by tracing the dark shade of irregular lines (appear like tree branches and roots) which are vaguely visible in the image.


(a) (b) (c)

Fig. 8: Samples of palm vein images from: a = prototype in this research, b = CASIA, and c = PolyU datasets.

The enhancement processing executed on the raw palm images revealed the palm vein pattern contained in the image, as compiled in Fig. 9. The white square in the image in Fig. 9 signifies the ROI extracted from the image to be enhanced. Vein pattern in the enhanced images is characterized by dark shades of irregular lines against a brighter background. It is observed that the vein pattern highlighted in the enhanced images is comparable for the three different datasets samples, regardless of the acquisition system. The outcome indirectly shows that the prototype developed in this research have the ability to record vein pattern in the acquired palm image.

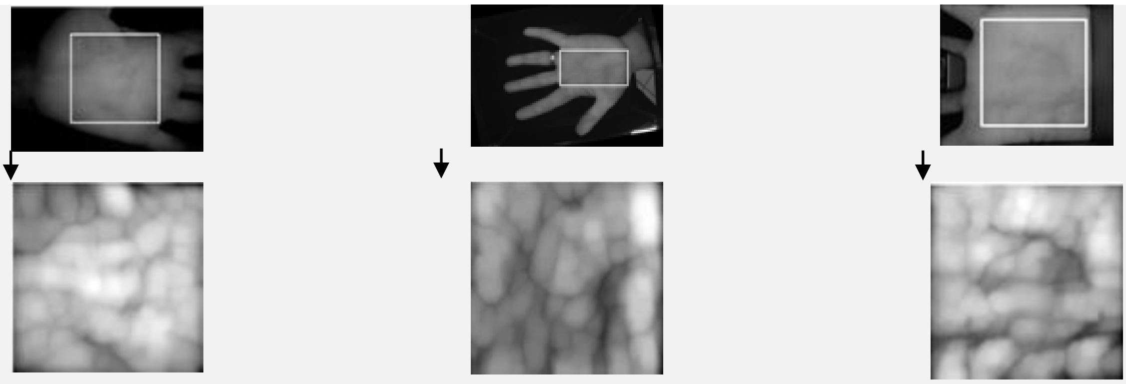

(a) (b) (c)

Fig. 9: Palm vein pattern revealed after the enhancement processing from: a = prototype in this research, b = CASIA, and c = PolyU datasets.

6.2. Vein image assessment

The enhanced palm images acquired by the prototype were assessed by the SNR and image contrast value to compare its quality with the other two datasets samples. 10 random palm from each datasets were assessed with six image samples each (total of 60 images), and the boxplot of the SNR and image contrast are shown in Figs. 10 and 11 respectively.

SNR distribution presented in Fig. 10 reveals that the SNR of enhanced images for PolyU dataset is generally higher that the other two datasets with median of 12.260, minimum of 10.270 and maximum of 13.140. Still, the distribution of SNR for the prototype and CASIA enhanced datasets are comparable, with median of 9.707 and 10.087 respectively. The SNR distribution of the enhanced images shows that although the dataset acquired by the prototype scores the lowest SNR, its distribution is close to the CASIA datasets distribution. It also shows that both datasets are affected by noise in its image owing to the uncontrolled surrounding (prototype dataset) and unguided acquisition nature (CASIA dataset).

Fig. 11 shows image contrast distribution of the enhanced images calculated by Michelson contrast equation in (1). It is observed from Fig. 11 that the contrast of the enhanced images for the prototype dataset has the highest median value (0.4996) compared to the other two datasets (CASIA: 0.3295, PolyU: 0.2088). The image contrast distribution of the prototype dataset is also the largest, with the highest contrast reaching the value of 0.9707. Whereas for the CASIA and PolyU datasets, the highest contrast value are 0.5280 and 0.3758 respectively. The image contrast distribution shows that the prototype dataset has the ability to acquire higher contrast image, compared to the other datasets.

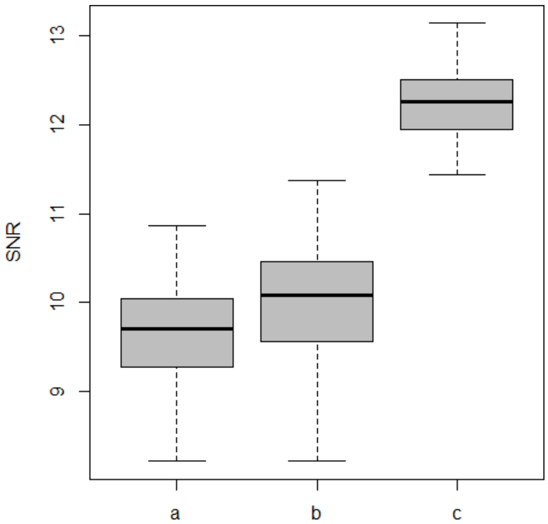


Fig. 10: SNR of the enhanced images from: a = prototype in this research, b = CASIA, and c = PolyU datasets.

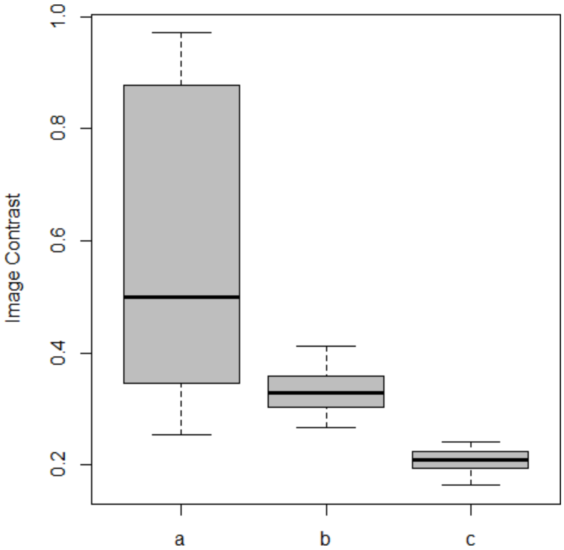


Fig. 11: Image contrast of the enhanced images from: a = prototype in this research, b = CASIA, and c = PolyU datasets.

Fig. 12 shows pixel-by-pixel similarity rate of vein pattern extracted from the three datasets. The vein was extracted by executing Laplacian filtering and adaptive thresholding on the enhanced images [27] as mentioned in the previous section. Samples of extracted vein pattern are given in Fig. 13 for each datasets. The extracted vein pattern is the white coloured pixels in the image, against a black background (non-vein features).

While perfect similarity can score up to 100% rate, the pixel-by-pixel comparison in Fig. 12 reveals that the prototype dataset has the highest median in the similarity rate distribution (96.48%). The prototype dataset also scores the highest similarity rate with its minimum of 94.09% to maximum of 97.71%. The CASIA dataset similarity rate is comparable to the prototype dataset, as its median is 96.07%, which is 0.41% less. However, the similarity rate distribution for CASIA dataset scores lower than the prototype, as its minimum rate is 93.02% while the maximum rate is 96.93%. The PolyU dataset scores the lowest of the three dataset, but its similarity rate distribution still indicates that the dataset has a comparable performance with the other two datasets (median: 90.99%).

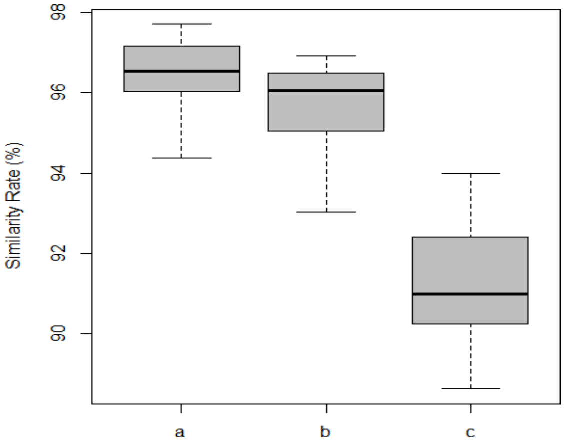


Fig. 12: Pixel-by-pixel similarity rate detection from: a = prototype in this research, b = CASIA, and c = PolyU datasets.

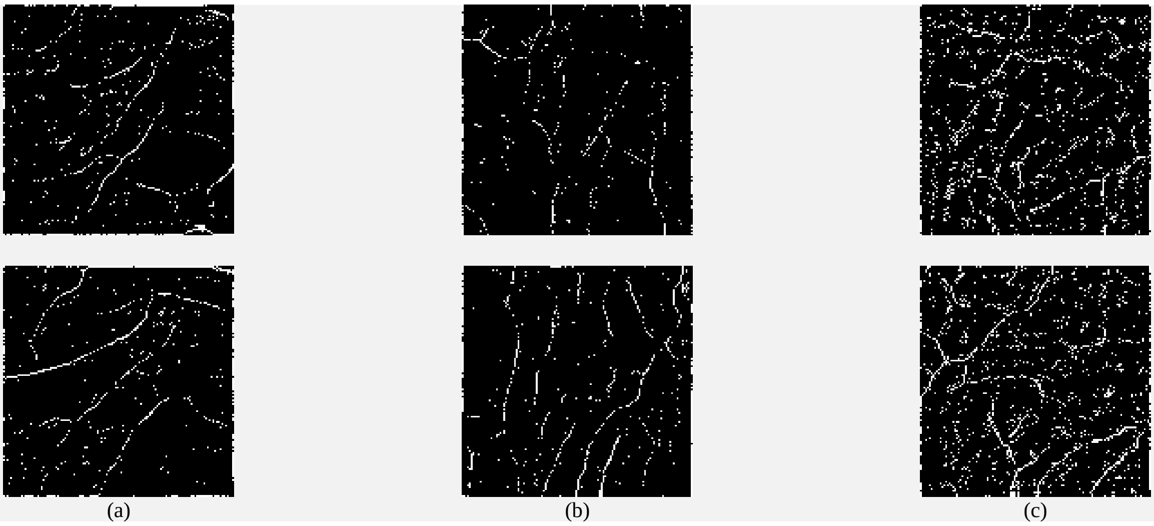

(a) (b) (c)

Fig. 13: Samples of extracted vein pattern from: a = prototype in this research, b = CASIA, and c = PolyU datasets.

7. Conclusion

In this paper, a palm vein imaging prototype had been developed using Raspberry Pi SBC. The main focus in the development is to produce a prototype that is readily adapted for embedded system environment without the need of additional controlled surrounding. The prototype GUI environment was developed by Python programming and the image analysis was done by OpenCV-Python module. Observation on the captured palm images revealed that the prototype had the ability to record vein pattern information based on the enhanced vein pattern after the enhancement processing. The prototype performance is comparable to the datasets acquired by CCD camera, gathered by the Chinese Academy of Sciences' Institute of Automation (CASIA) and the Hong Kong Polytechnic University (PolyU). The performance can be seen in terms of the presented SNR and image contrast of the enhanced images. Furthermore, when the vein pattern is extracted and matched against its reference image, the pixel-by-pixel similarity rate of the prototype dataset is distributed at higher values than the other two datasets with median value of 98.48%. In contrast, the median value of CASIA and PolyU datasets are 0.41% less and 5.49% less respectively.

Even so, the analysis was based on 10 random palms with six samples each, totaling to 60 images for each datasets. In future work, the number of random palms for the analysis will be increased to determine if the number of random palms affect the similarity rate of the detected vein pattern. Still, the analysis presented in this paper provides a good starting point as motivational launch to venture further into this research.

The prototype development in this paper is shared with the hope to provide optional tools for researchers in developing their own work in the field of biometrics and medical applications, specifically involving vein imaging. The developed prototype can be extended its usage as security system embedded for domestic, educational or commercial application alike.

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